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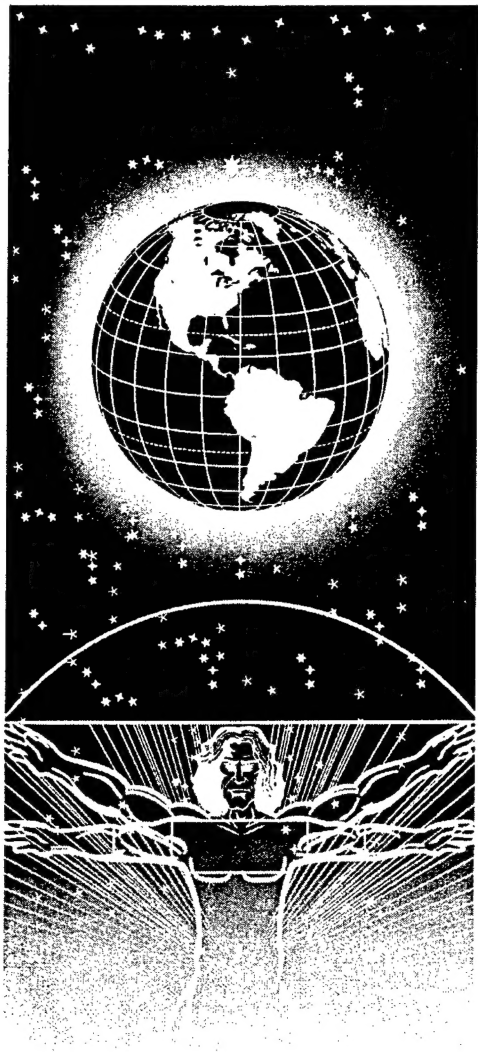

UNITED STATES AIR FORCE RESEARCH LABORATORY

EFFECT OF PROJECTION VISOR TRANSMISSIVITY AND REFLECTIVITY LEVEL ON VISUAL ACUITY IN LOW LIGHT CONDITIONS

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

John Reising

JOHN M. REISING
Crew System Interface Division
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The purpose of this study was to determine the effect of projection visor transmission and reflection properties on a pilot's ability to detect a visual target. Five visor configurations were used to analyze the effect of transmissivity. They were no visor, a visually coupled acquisition and targeting systems (VCATS) 50% visor, VCATS 35% visor, VCATS 25% uncoated visor, and a standard USAF 12% visor. Two visors were used to analyze the effect of reflectivity. They were a VCATS 25% uncoated visor and a VCATS 24% coated visor. Results showed there was a reduction in mean target detection range with a decrease in visor transmissivity except for the paring of no visor to the VCATS 50% visor and the VCATS 35% visor to the VCATS 25% uncoated visor. In these two comparisons no statistical significance was found in detection range. No statistical significance was found in the detection range for the visors used in the reflectivity analysis.

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ABSTRACT

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The purpose of this study was to determine the effect of projection visor transmission and reflection properties on a pilot's ability to detect a visual target. Five visor configurations were used to analyze the effect of transmissivity. They were no visor, a visually coupled acquisition and targeting system (VCATS) 50% visor, VCATS 35% visor, VCATS 25% uncoated visor, and a standard USAF 12% visor. Two visors were used to analyze the effect of reflectivity. They were a VCATS 25% uncoated visor and a VCATS 25% coated visor. Results showed there was a reduction in mean target detection range with a decrease in visor transmissivity except for the pairing of no visor to the VCATS 50% visor and the VCATS 35% visor to the VCATS 25% uncoated visor. In these two comparisons no statistical significance was found in detection range. No statistical significance was found in the detection range for the visors used in the reflectivity analysis.

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CHAPTER I

INTRODUCTION

Background of the Problem

Since the introduction of air-to-air missiles, aircraft and missile designers have been searching for methods to improve integration with avionics and fire control systems to expand the weapons engagement zone (WEZ) of the weapons. The WEZ, also referred to as the launch acceptability region, is the region that a fighter aircraft must maneuver into in order to employ weapons against a target aircraft to ensure adequate sensor acquisition and kinematic capability in relation to the target. While the weapons themselves have continually evolved, the mechanisms to aim these missiles have been limited to the aircraft's fire control radar (FCR) and the heads-up-display (HUD). Both systems offer a huge advantage over an adversary that is not similarly equipped, however, both have significant limitations in relation to the capability offered by the latest generation of high off-boresight weapons. Off-boresight is the term used to describe the angular difference between the longitudinal axis of the aircraft and the boresight of the cueing source.

Current Weapons Aiming Mechanisms

The current, highly dynamic, air-to-air fighter combat environment requires weapons and cueing systems that are capable of slaving at rates of several hundred degrees per second and at off-boresight angles in excess of 90 degrees. The introduction of helmet mounted cueing systems has expanded the

WEZ well beyond the FCR and HUD capability and allows the pilot to employ off-boresight weapons to their full potential.

Fire Control Radar

The FCR was the first system integrated to provide the capability to slave weapons off-boresight. Using the FCR, a pilot is provided the capability to slave both weapons and sensors to the radar's line-of-sight. However, the FCR is not optimized for the current dynamics of the within-visual-range (WVR) arena. The FCR cueing system has relatively slow slaving rates, long delays associated with the transition from target acquisition to track and fixed scan patterns that force the pilot to maneuver his aircraft into specific positions in order to obtain a radar track. Additionally, once the radar is in track, current FCRs' off-boresight capabilities are limited to between 60 and 70 degrees, thus limiting the new generation of weapons (McDonnell Douglas Aerospace, 1997).

Heads Up Displays

The introduction of the HUD in the 1950s provided the ability to display dynamic aiming references for both the gun and missiles by projecting symbology onto a combining glass mounted directly in front of the pilot. Instead of having to look inside the cockpit to determine aircraft and weapons parameters, the pilot could look outside the cockpit through the HUD and obtain valuable cueing information while still maintaining situational awareness outside the cockpit (Adam, 1995).

Although integration of a HUD provides a quantum leap in weapons employment capability, it still has limitations, primarily because it is fixed to the

aircraft and provides a limited field of view to the pilot. To aim a weapon using the HUD, the pilot must maneuver to bring the target into the HUD field of view, which is fixed along the aircraft's boresight. The result is the loss of the high off-boresight capability of the weapon (Adam, 1995).

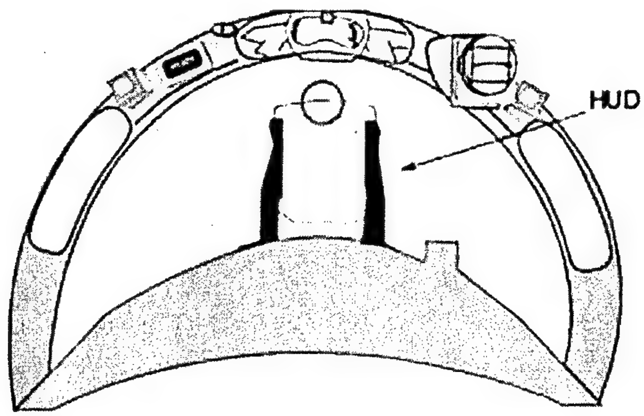


Figure 1. Heads Up Display.

Helmet Mounted Systems

A logical solution to the off-boresight limitations of the FCR and the HUD was to design a helmet mounted cueing system that allowed the pilot to aim weapons where he was looking by simply pointing the boresight of the helmet at the target aircraft. Currently there are two categories to classify helmet mounted cueing systems. They are the helmet mounted sight (HMS) and the helmet mounted tracker and display (HMT/D). Both systems allow the pilot to aim sensors and weapons, but the HMT/D goes a step further by displaying the symbology that is normally available to the pilot through the HUD, as well as additional information, projected on the helmet visor in front of the pilot's eyes (Adam, 1995).

Helmet Mounted Sights

The HMS is the most basic helmet mounted cueing system. Its primary purpose is to display designated targets for sensor or weapon acquisition. There are two major components of a HMS system: an aiming device and a helmet tracker. The aiming device can be as simple as a crosshair on the helmet visor or a small combining glass positioned in front of the pilot's eye. The helmet tracker is simply a means to determine the helmet line-of-sight. To use the HMS, the pilot puts the aiming device on a target and then commands the sensor or weapon to slave to the helmet line-of-sight, acquire, and track the target (Adam, 1995).

Helmet Mounted Displays

While a HMS system is useful for aiming high off-boresight weapons, it lacks the flexibility to display HUD type information directly in front of the pilot's eyes. A HMT/D adds a graphics display device, usually in the form of a cathode ray tube (CRT), to a HMS to provide this capability. The CRT image is projected onto the helmet visor, which in turn reflects the image back to the pilot, thus providing the pilot with a HUD-like image displayed directly in front of his eyes (Gunther, 1995).

HMT/Ds offer the advantages of a HUD without the limitation of being fixed to the aircraft. Regardless of where the pilot is looking, there is a heads-up display on the visor. High off-boresight weapons can be aimed and proper tracking verified by simply looking at the target. This capability comes at a cost, however. For the system to operate the pilot must be wearing a visor and the

visor must possess some degree of reflectivity so that the CRT image can be reflected back into the pilot's eye. The reflectivity of the visor can be inherent to the design of the visor or can be achieved by applying a reflective coating to the inner surface of the visor. The combination of the visor and the reflective coating reduce the amount of light that reaches the pilot's eyes and can decrease the amount of desired light transmitted to the pilot's eyes. (Kocian, 1999).

Problem Statement

To regain parity with the current threat, a helmet mounted cueing system is required for target acquisition and off-boresight ordnance employment. A helmet mounted cueing system requires a pilot to wear a projection visor. The darker the visor, the better for projection symbology display. Experience shows there is a perceived degradation in visual acquisition and aspect determination when a dark visor is worn. Recent research shows this to be true in a blue sky, high illumination environment. Experience tends to indicate a greater degradation in a lower illumination environment such as overcast, dusk, and dawn. This research provided data in a low illumination environment to help determine acceptable reflectivity and transmissivity thresholds for projection visors in relation to a pilot's visual acuity. Specifically, the researcher determined the level of transmissivity and reflectivity impact on visual detection range in a low light environment.

Researcher's Work Setting and Role

The researcher is an F-15C fighter instructor pilot with approximately 3,000 hours in F-15 and F/A-18 aircraft combined. He is a graduate of the United

States Air Force Fighter Weapons School and is currently stationed at Nellis AFB, Nevada as the Chief of Training for the Air Warfare Center. In this capacity, the researcher flies regularly with the 422 Test and Evaluation Squadron (422 TES). The 422 TES F-15C division is the leading operational test activity in the Air Force for the next generation HMT/D. The 422 TES currently has four F-15C aircraft modified for compatibility with either the Visually Coupled Acquisition and Targeting System (VCATS) or Joint Helmet Mounted Cueing System (JHMCS).

Limitations and Assumptions

This research was conducted as a follow-on to a prior study (Silva 2001) of the effects of transmissivity and reflectivity on visual acuity in a blue sky, high light environment. Due to the limited time that low light conditions existed for the purpose of the study, the testing was conducted with runs using no visor, a standard Air Force tinted visor, a VCATS uncoated 25% transmissive visor, a VCATS coated 25% visor, a VCATS uncoated 35% visor, and a VCATS 50% transmissive visor. The selection of these conditions is based on the results of the previous study (Silva 2001).

CHAPTER II

REVIEW OF RELEVANT LITERATURE AND RESEARCH

A discussion of the basic physical properties of light as they apply to visor study leads to a discussion of helmet mounted display (HMD) mechanization in fighter aircraft. A historical review of previous and current U.S. HMD programs is presented and the discussion curtails into the visual acuity research which has been accomplished. Also considered are the results from the previous display visor visual acuity research accomplished in clear blue sky, high light conditions of which this research is complimentary.

Properties of Light

A basic knowledge of the properties of light as related to viewing by the human eye through a transparent medium is vital in understanding the complexities of HMD design. Military visors commonly use plastic material for their composition, usually polycarbonate. Plastic has many desirable qualities however, it has several undesirable qualities not normally associated with glass. These effects include rainbowing, multiple imaging, distortion, and haze (Kocian & Task, 2000).

Light that is incident on a transparent surface can be absorbed, reflected, scattered, or transmitted as is illustrated by the visor surface shown in Figure 2.

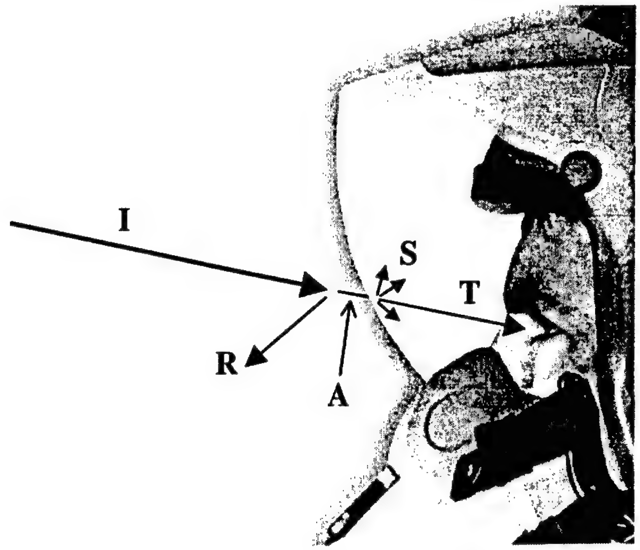


Figure 2. Light Incident to a Transparent Surface (I) is Absorbed (A), Reflected (R), Scattered (S), and Transmitted (T). Note. From The Impact of Visor Transmissivity and Reflectivity on Pilot Visual Acuity and Target Acquisition Range (p. 5), by D. Silva, 2001, Nellis AFB: Graduate Research Proposal presented to Embry-Riddle Aeronautical University. Reprinted with permission.

Image forming potential is maintained only by transmitted and reflected light. The light that actually passes through the visor consists of transmitted and scattered light. Scattered light passing through the visor produces an undesirable effect referred to as veiling luminance due to haze. The National Bureau of Standards (NBS) defines haze as the ratio of scattered light (S) to the total light (S + T), equation 1, coming through a transparent surface (Task & Genco, 1985).

$$H = \frac{S}{S + T} \tag{1}$$

Haze causes a reduction in the contrast between a target and the surrounding background. The contrast between a target and the background when not viewed through a transparent surface is defined in equation 2. The contrast due to haze when viewing the same target and background through a transparent surface, is defined in equation 3. The result of haze is a reduced capability to discern targets from the background (Task & Genco, 1985). To a pilot, this translates into reduced target visual detection range and a tactical disadvantage.

$$C = \frac{|L_T - L_B|}{L_T + L_B} \tag{2}$$

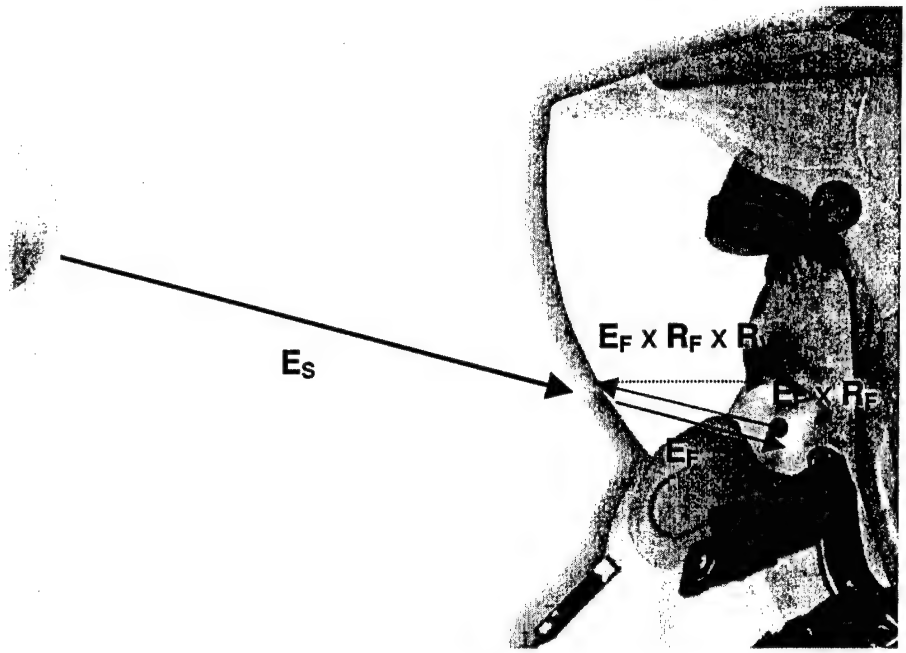
C = Contrast
L_T = Target luminance
L_B = Background luminance

$$C_H = \frac{C}{1 + 2\dfrac{L_H}{(L_T + L_B)*T_V}} \tag{3}$$

C_H = Contrast due to haze
L_H = Veiling luminance due to haze
T_V = Visor transmission

The total light reaching the pilot's eyes when looking through a visor is made up of four components. They are the light from the target of interest, light from the background, scattered light, and unwanted reflected light. This unwanted reflected light is caused by the reflective properties of the pilot's face and the reflective properties of the visor. As light passes through the visor, some of it reflects off the pilot's face. A portion of this light is subsequently reflected off

the inside of the visor and back into the pilot's eyes (Figure 3). This extraneous reflected light can also act as a distraction to the pilot (Kocian & Task, 2000).



E_S = Illuminance at visor from sun
E_F = Illuminance at face from sun
R_F = Face diffuse reflectance coefficient
R_V = Visor reflection coefficient

Figure 3. Extraneous Reflected Light Inside the Visor. Note. From The Impact of Visor Transmissivity and Reflectivity on Pilot Visual Acuity and Target Acquisition Range (p. 7), by D. Silva, 2001, Nellis AFB: Graduate Research Proposal presented to Embry-Riddle Aeronautical University. Reprinted with permission.

HMD Mechanization

One HMD system purpose is to display tactical information to the pilot with a minimum of degradation to the pilot's visual acuity outside the visor environment. Through the use of a cathode ray tube (CRT) a HMD projects images onto a visor. The image generated by the CRT is collimated and

projected onto the helmet visor which, in turn, reflects the image into the pilot's eye as shown in Figure 4 (Jackson, 1998).

For the image to be visible to the pilot, a certain amount of light must be reflected off the visor and directed into the pilot's eyes. The light projected from the CRT will hit the visor and will be reflected, absorbed, scattered, and transmitted due to the fact that the visor is not designed to be a perfect reflector, thus exhibiting the properties of a transparent surface as discussed earlier. The result is a lower level of light reaching the pilot's eye than is being projected from the CRT. Figure 5 depicts what happens to the light transmitted from the CRT.

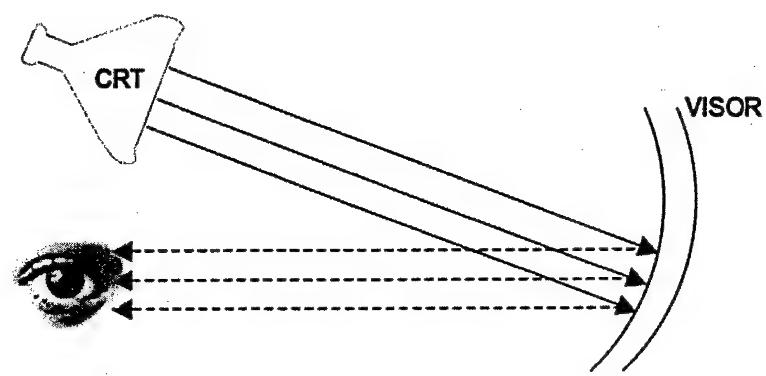


Figure 4. Reflected Light from the CRT.

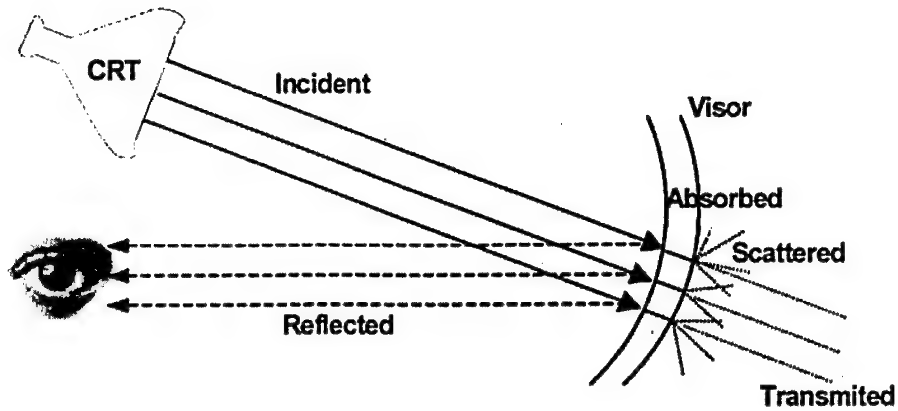


Figure 5. Reduction in Reflected Light Due to Absorption, Transmission, and Scattering.

There are two ways to increase the amount of light that is actually reflected into the pilot's eyes. First is an increase in the reflectivity of the inside surface of the visor. Second is to increase the output power of the CRT. Either one of these solutions has tradeoffs. An increase in the reflectivity of the inside surface of the visor decreases the amount of light transmitted from outside the visor and increases the amount of extraneous light from unwanted reflections. The loss of transmissivity can be calculated by using equation 4 (Kocian and Task, 2000). The result of increased reflectivity is reduced visual acuity outside the cockpit.

$$T_{VC} = T * (100 - R_{VC}) \qquad (4)$$

T_{VC} = Visor transmissivity with reflective coating
T = Visor transmissivity uncoated
R_{VC} = Reflectivity of visor coating

The desire for a more transmissive visor would mean an increase in the CRT power output to maintain a usable image projection. The requirement for higher power output leads to increased size and weight of the CRT and higher failure rates for the components based on today's technology. In addition, a higher power CRT combined with a low reflective visor can create a problem with double imaging, known as ghosting. Figure 6 shows that as light strikes the visor, some will be reflected off the inner surface and some will be reflected off the outer surface of the visor. The result is two images reflected into the pilot's eyes, a primary image and a ghosted image (Kocian, 1999).

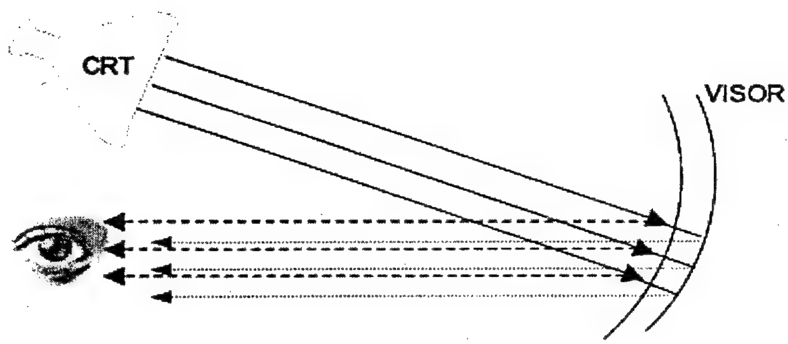


Figure 6. Double Images, Ghosting Due to Light Being Reflected Off the Inner and Outer Surfaces of a Visor.

U.S. HMD Programs

From August 1986 to July 1992, the Human Engineering Division of Armstrong Laboratory (AL) conducted a series of simulations designed to quantify USAF helmet mounted tracker and display (HMT/D) requirements. The

simulation program was called Vista Sabre and demonstrated a 50:1 kill ratio when pilots employed using the Kaiser Electronics, Agile Eye HMT/D. Subsequently, the USAF approved an operational flight test in response to the success of Vista Sabre. The purpose of this flight test program, named Vista Sabre II, was to assess the utility of the Agile Eye HMT/D with a high off-boresight angle (HOBA) missile in an air-to-air engagement (Kocian, 1999).

The Vista Sabre II test was very successful, however, it highlighted several deficiencies of the Agile Eye HMT/D system. The Agile Eye HMT/D was replaced in 1996 by the Visually Coupled Acquisition and Targeting System (VCATS). The Air Force Research Laboratory (AFRL), (formerly Armstrong Laboratory), in conjunction with Kaiser Electronics and McDonnell-Douglas Aircraft, built on the lessons learned from Vista Sabre II to produce a more operationally representative HMT/D. VCATS continued to build on the Vista Sabre II lessons and has fed valuable information to the Joint Helmet Mounted Cueing System (JHMCS) which began testing in 1999 and is programmed to become operational in the USAF in 2002 (Kocian, 1999).

Vista Sabre II

Vista Sabre II consisted of modifying two 422 TES F-15Cs to accommodate the Kaiser Electronics Agile Eye, Agile Eye Plus, Agile Mark III and Mark IV HMT/Ds. The first flight with the Agile Eye was in April 1993 and testing began in October 1995. The Agile Eye was a lightweight, full function, monocular, stroke display HMT/D system. It used a modified USAF HGU-55/P helmet, which displayed data on the visor in front of the pilot's right eye through a

15 to 20 degree field-of-view. Table 1 describes the different combinations of visor transmissivity and reflectivity that were tested on the Agile Eye helmets. It should be noted that the transmission levels in Table 1 are the values before the reflective coating was added (Silva, 2001).

Table 1

Vista Sabre Visor Transmissivity and Reflectivity

	Visor Transmission	Reflective Coating
Agile Eye Mark III	Clear - 100%	30% patch
Agile Eye Mark III	Tinted - 13%	18% patch
Agile Eye Mark IV	Clear - 100%	30% patch
Agile Eye Mark IV	Tinted - 13%	18% patch
Agile Eye Mark IV	Tinted - 25%	18% patch

The patch used on the Agile Eye HMT/D was an oval reflective patch that was placed onto the visor in front of the pilot's right eye. The patch was used to provide a reflective surface for the field of view of the HMD without having to coat the entire visor with the reflective material. During testing a significant visual problem was discovered. A brighter light condition existed in the majority of the visor surface that was not coated causing the pilots eyes to adjust to this condition. When the pilot brought the target into the coated area, it disappeared against the darker background. It took the pilot's eye time to adjust to the new light condition and reacquire the target in the patch area. The result was

significantly reduced target acquisition ranges within the display portion of the HMD. The recommendation from the Vista Sabre II final test report was to design an HMD that did not require a patch (Olson, 1996a).

Visually Coupled Acquisition and Targeting System (VCATS)

The primary purpose of the VCATS program was to capitalize on lessons learned from Vista Sabre II and build a completely redesigned HMT/D. This project would serve as a risk reduction model for the USAF's future HMT/D, the Joint Helmet Mounted Cueing System (JHMCS). Besides serving as a technology demonstrator, the project would also provide the combat pilots perspective on the actual use of the system in simulated combat using high off-boresight seekers (HOBS) for missile interface, and prepare/maintain proficiency for operational testing of JHMCS (Olson, 1996b) The VCATS test began in 1997 and testing continues by the 422 TES at Nellis AFB, Nevada.

A major goal of the VCATS program was to determine the optimum combination of optical hardware, visor transmissivity and visor reflectivity. The problems with visor reflectivity discovered with the Agile Eye HMT/D led AFRL to pursue a more powerful CRT for VCATS. The result was a "hot tube" design that increased the working voltage of the CRT from the 8 kilovolts used in previous HMD systems to 11.8 kilovolts. The corresponding increase in power allowed more flexibility in the design of the visor, particularly a reduction in the required reflectivity (Kocian, 1995).

The solution to the problems created by the patch from Vista Sabre II was to use a visor that had a reflective coating applied to the entire visor. This

allowed the pilot's eye to view a uniform area and adjust to just one light level. Table 2 describes the different combinations of transmissivity and reflectivity used on the VCATS visors (Silva, 2001).

Table 2

VCATS Visor Transmissivity and Reflectivity

Visor Transmissivity (Before Coating Added)	Reflective Coating	Visor Transmissivity (After Coating Added)
Tinted - 25%	9%	22.5%
Tinted - 25%	6.5%	23.5%
Tinted - 25%	Uncoated (4% reflectivity)	25%
Tinted - 35%	Uncoated (4% reflectivity)	35%

The uniform visor solved the problem of the eye needing to adjust to different light condition of the patch, however, a new problem was discovered. The coating on the early VCATS visors was so reflective that the pilots could see their own facial features on the visor (Olson, 1996a). Additionally, the reflective coating reduced the visor's initial 25% transmissivity as shown in Table 2. The resultant effects of the reflections combined with reduced transmissivity led the pilots to report a significant reduction in their visual acuity, target visual acquisition ranges and overall combat effectiveness. In reduced lighting conditions, such as at dusk or when flying under an overcast, the dark visor became even more difficult to use (McComas, 1998).

A solution was attempted using a completely uncoated visor. The uncoated visor provided an inherent 4% reflectivity, 25% transmissivity level, and was compatible with the "hot tube" CRT. A follow-on to the 25% uncoated visor was a 35% uncoated visor. Using the new visor configurations, the pilots reported a significant improvement in target detection ranges and overall combat capability (McComas, 1998).

JHMCS

The culmination of the years of development and testing of HMT/Ds have resulted in production and prototype testing of the Joint Helmet Mounted Cueing System. JHMCS is the HMT/D that will be produced for operational U.S. Air Force and U.S. Navy units. JHMCS is scheduled to be deployed on the F-15, F-16, F/A-18, and F-22 aircraft. Prime contractors for this effort are Boeing and Lockheed Martin. The JHMCS system completed initial flight demonstration testing on both the F-15 and F/A-18 in late 1998 at Edwards AFB, California and China Lake, California respectively (Sillia, 1998).

JHMCS testing continues on F-15s from the 422 TES at Nellis AFB, Nevada and on F/A-18E/F at the Naval Air Warfare Center, Weapons Division, China Lake, California. Boeing has received a $10.4 million contract begin low-rate initial JHMCS production for the U.S. Navy (Blecher, 2000).

Visual Acuity Research

There has been much debate about the effects of sunglasses and visors as pertains to visual acuity in the aerial combat environment ever since aircrews

have used these devices. Both the Navy and Air Force have conducted studies on this subject.

U.S. Navy Research

In 1991 the Navy conducted a study of 126 Navy fighter pilots obtaining data on visor wear habits, vision test data, and evaluative comments. The interviews revealed that pilots varied in their personal use of the helmet sun visor. The study found some pilots use it all the time, some only during certain flight conditions, and some never use it. The study further tested low-contrast spot detection, acuity, and contrast sensitivity measured in realistic daytime illumination levels in subjects viewing through filters ranging from 6.3% to 50.1% transmission (Standard visor transmission is 12+/-4%.). Results showed that filter density, and consequently the illuminance reaching the eyes, could be varied over a wide range without critically affecting these visual functions (Morris, Temme, & Hamilton, 1991) An additional Navy study found pilots using the standard 12% filter aviator sunglasses experienced a 5% loss in visual acquisition ranges (Marsh, Cushman, & Temme, 1991).

U.S. Air Force Research

In 1985, Task and Genco published a report expanding on the National Bureau of Standards definition of haze. Haze is the loss of scene contrast encountered when light is scattered off of a transparent surface. Their study found as the transmission properties of a transparent surface decreased, there was a corresponding loss of scene contrast (Task & Genco, 1985).

A complimentary study was conducted by Kocian and Task at the Air Force Research Laboratory in February 2000. The purpose of this study was to determine the effects of reflective coatings on visual acuity when applied to a visor. Kocian and Task derived the following equations to determine the theoretical contrast for a visor without a reflective coating (Equation 4) and for a visor with a reflective coating applied (Equation 5).

$$C_U = \frac{C}{1 + 2(E_S * R_F * R_V)/(L_T + L_B)} \tag{4}$$

$$C_C = \frac{C}{1 + 2(E_S * R_F * R_{VC})/(L_T + L_B)} \tag{5}$$

Where:

C = Contrast (equation 2)
C_U = Contrast - uncoated visor
C_C = Contrast - coated visor
L_T = Target luminance
L_B = Background luminance
R_F = Face diffuse reflectance coefficient
R_V = Visor reflection coefficient - no coating
R_{VC} = Visor reflection coefficient with coating
E_S = Illuminance at visor from sun

Through the use of these equations, Kocian and Task were able to determine the theoretical contrast of a target against a blue-sky background when viewed without a visor and when viewed through two visors, one reflectively coated and the other not coated. The uncoated visor had inherent 3.5% reflectivity while the second visor had 13% reflective coating. Table 3 shows the results against a blue-sky background and Table 4 shows results against a ground background environment. Contrast reduction is compared on a percentage basis (Kocian & Task, 2000).

Table 3

Target vs. Blue Sky Contrast Example

Contrast Condition	Contrast Value	Contrast Loss (%)	Contrast Loss (%)
No Visor	0.33	Baseline	
Uncoated Visor	0.27	18.9	Baseline
Coated Visor	0.19	46.4	33.9

Input Values:
$L_T = 300$ ft-L $R_V = 0.035$
$L_B = 600$ ft-L $R_{VC} = 0.13$
$E_S = 1000$ ft-c $R_F = 0.3$

Table 4

Target vs. Ground Contrast Example

Contrast Condition	Contrast Value	Contrast Loss (%)	Contrast Loss (%)
No Visor	0.23	Baseline	
Uncoated Visor	0.18	23.7	Baseline
Coated Visor	0.11	53.6	39.2

Input Values:
$L_T = 100$ ft-L $R_V = 0.035$
$L_B = 160$ ft-L $R_{VC} = 0.13$
$E_S = 3850$ ft-c $R_F = 0.3$

Kocian and Task note that the theoretical results show that a change in contrast is obtained as the surface reflectivity increases, and that the percentage loss does not match the percentage increase in the surface reflectivity. Compared to no visor, the uncoated visor caused a contrast loss of 18.9% and

23.7% against a blue-sky and ground background respectively. Compared to the same baseline, the coated visor caused a contrast loss of 46.4% and 53.6% (Kocian & Task, 2000).

They also note this analysis understates the problem by assuming the only effect is a loss of contrast from the veiling (reflection-induced) luminance. In reality, the visor reflections are not uniform veiling luminances but have some structure since they are reflections from different facial features. This structure may further degrade vision by serving as a masking pattern, a distraction, and/or an accommodative trapping mechanism (Kocian & Task, 2000).

Statement of the Hypothesis

A pilot is required to wear a projection visor to optimize current helmet mounted cueing system symbology. In order for the pilot to see the symbology and maximize use of the system the visor must possess some level of transmissivity and some degree of reflectivity. The combination of the visor and the reflective coating reduce the contrast ratio between the target and the surrounding background. This reduction may be significantly larger in a low illumination environment when compared to high illumination blue-sky environment. This study tested two hypotheses.

It was hypothesized that the target detection range of USAF F-15C, A-10, and F-16 pilots would decrease as the transmissivity of the visor was decreased in a low illumination environment. It was also hypothesized that the target detection range of USAF F-15C, A-10, and F-16 pilots would decrease as the reflectivity of the visor was increased in a low illumination environment.

CHAPTER III

RESEARCH METHODOLOGY

Research Design

The researcher used an experimental approach to determine the effect of visor transmissivity and visor reflectivity on target acquisition range in a low illumination environment. Six different visor configurations were used.

Research Model

The test population consisted of 12 F-15C, A-10, and F-16 pilots. The study determined if visor transmissivity and visor reflectivity affected visual acuity, measured by target detection range. The test design allowed the researcher to control critical external conditions such as lighting conditions and background to target contrast ratio.

Pilots were tested under similar environmental conditions using six different visor configurations: no visor, a standard USAF tinted visor (USAF standard), a VCATS uncoated 25% transmissive visor (VCATS 25% uncoated), a VCATS 6.5% reflective coated 25% transmissive visor (VCATS 25% coated), a VCATS uncoated 35% transmissive visor (VCATS 35% uncoated), and a VCATS uncoated 50% transmissive visor (VCATS 50% uncoated). Table 5 depicts the different transmissive and reflective properties of each visor configuration. Testing was accomplished during low illumination conditions.

Table 5

Experimental Visor Transmissivity and Reflectivity

	Transmissivity	Reflective Coating	Reflectivity
No Visor	100%	None	0%
USAF Standard	12%	None	4%
VCATS 25% Uncoated	25%	None	4%
VCATS 25% Coated	23.5%	6.5%	6.5%
VCATS 35% Uncoated	35%	None	4%
VCATS 50% Uncoated	50%	None	4%

Note. Transmissivity of coated visor derived using equation 4.

To determine the effect of transmissivity on visual acuity, target detection ranges were compared as the transmissivity of the visor configuration was varied. Detection ranges were measured using a random visor configuration order including a VCATS 50% uncoated, VCATS 35% uncoated, VCATS 25% uncoated, and the USAF standard visor.

To determine the effect of reflectivity on visual acuity, target detection ranges were compared between the VCATS 25% uncoated visor and the VCATS 25% coated visor. Although the transmissivity of the VCATS 25% coated visor is 1.5% less than the VCATS 25% uncoated visor, the major difference is the 6.5% reflective coating added to the VCATS 25% coated visor. The effect of this small difference in transmissivity between these two visors is negligible when compared to the difference in reflective coating (D. Silva, personal communication, April 30, 2001).

Test Population

The population used in this study consisted of 12 pilots currently assigned flying duties in the 422 TES at Nellis AFB, Nevada. The pilots were current and qualified in either the F-15C, A-10, or F-16 aircraft. Study pilots were not required to be qualified to fly with a HMT/D. Having a HMT/D qualification did not impact the test data. Study pilots were only required to wear a helmet and conduct test runs wearing the six visor configurations.

This test used a convenience population of 12 pilots. The choice of a convenience population of 12 was based on several factors. First, pilots assigned to the 422 TES are a representative sample of all the F-15C, A-10, and F-16 pilots in the USAF. Vision requirements are standardized throughout the USAF and pilots must maintain a visual acuity of at least 20/20. Assignment to the 422 TES is not dependent on visual acuity nor is their visual acuity affected by assignment to the 422 TES. The convenience population of 12 pilots from the 422 TES represents a random sample of the visual acuity of pilots in the USAF.

The second factor is the constraint of time and money. It was impractical and not cost effective to increase the population size. Data were collected within 60 days to allow time for processing and analysis. There was no funding for this study when conducted, therefore a local representative population was required. A subjective analysis of risk reduction by including a larger population based on these factors made it negligible for the purpose of this study.

The final factor determinant in the choice of this population was to compliment a prior study, conducted by Silva, upon which this study is based. In

that study a convenience population of 12 pilots from the 422 TES was used. The study conducted was similar to this study with the major difference being the background lighting conditions. Conclusions from the two studies will be compared for consideration by the Air Force Research Laboratory in selection of an optimum projection visor for production models of the JHMCS HMT/D system.

Sources of Data

Data for this study are quantitative, collected from test runs and recorded on a worksheet, then entered into a Microsoft Excel spreadsheet. The results of this study and Silva study will then be compared and analyzed by scientists at AFRL.

Data Gathering Device

The procedural conduct of this test was almost identical to the study conducted by Silva with differences in illumination conditions, an addition type of visor to be tested, and three runs per visor configuration versus five conducted in the Silva study. The test was accomplished by using a Four Alternative Detection Task device mounted on a testing board. The board was covered with a blue background to simulate a clear blue sky. A F-15C silhouette was placed randomly on the board facing in a random direction: up, down, right, or left (Figure 7). The silhouette was a 500:1 scale representation and was colored aircraft gray simulating the actual paint scheme of the F-15C. The testing board was mounted on a stand ensuring a constant 90 degree angle.

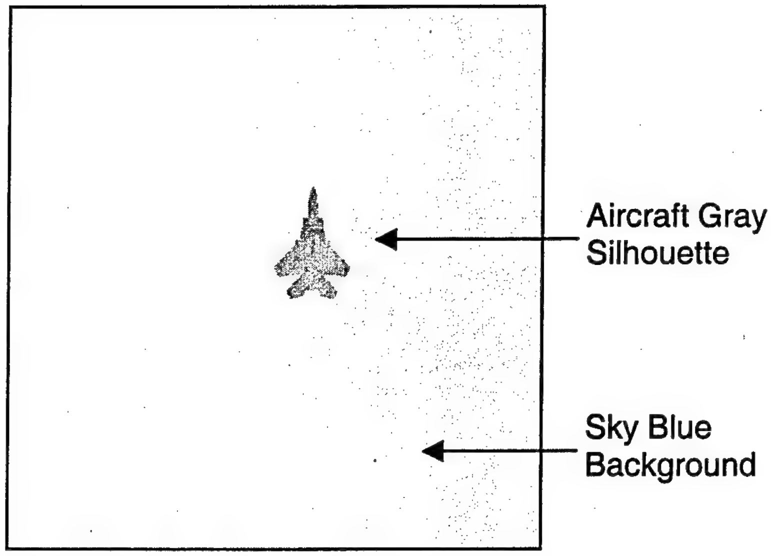


Figure 7. Depiction of Example Configuration of the Four Alternative Forced-Choice Target Detection Task Testing Board. Note. From The Impact of Visor Transmissivity and Reflectivity on Pilot Visual Acuity and Target Acquisition Range (p. 24), by D. Silva, 2001, Nellis AFB: Graduate Research Proposal presented to Embry-Riddle Aeronautical University. Reprinted with permission.

For each pilot, the test consisted of three runs each wearing the six different visor configurations for a total of 18 runs. The aircraft silhouette direction was randomly changed between each run to ensure the pilot actually acquired the target. The order in which the visor configurations were tested was determined randomly for each pilot using the random number generator from Microsoft Excel. The test area was marked off in one foot increments providing a mechanism for measurement of detection ranges.

The test was conducted with the pilot sitting in a chair at the zero foot line. He was wearing one of the six visor configurations as randomly selected. The testing board was covered and located 50 yards away from the location of the pilot. This placed the board at a range beyond the pilot's ability to detect the

target. The cover was removed from the test board and the board was moved toward the pilot at a constant rate of three feet per second. Using a 500:1 scale, this rate of closure closely simulated the rate of closure experienced during a typical air-to-air engagement which is approximately 15 nautical miles per minute. When the pilot determined the target's direction, he said stop and declared which direction the silhouette was pointing. If the pilot was correct the range of the board was noted and that run was terminated. If the pilot was wrong the board continued to be moved closer until the correct direction was declared.

Each set of test runs was conducted with approximately the same environmental conditions. Testing began approximately 30 minutes prior to official sunset as the sun went behind the 422 TES building, but prior to the sun going behind the horizon. This provided for a controlled low light environment. This testing was conducted between the months of June and August.

To ensure consistent lighting conditions, a photometer was used to measure the light conditions at termination of the first and final runs. Measurements were taken on the brightness of the target and on the brightness of the background. These two measurements were used to determine scene contrast. A reading taken from a barium plate determined the overall lighting conditions. These measurements were used to ensure the test was conducted under similar contrast and light conditions. An acceptability boundary condition of a 2:1 ratio was applied to the light conditions for each pilot's testing (L. Task, personal communication, May 14, 2001)

Pilot Study

A pilot study for this particular study was not conducted however, lessons learned from the conduct of the study conducted by Silva were incorporated into this study. Results from this and the Silva study will be used to determine a course of action for procurement of production projection visors for the JHMCS system.

Pretest

Experimentation method and data collection design for this study are based on validation by the Silva study. A pretest of light conditions was conducted prior to experiment execution.

Reliability

Pilots completed three runs each with each of the six visor configurations to ensure consistency. Data were gathered under environmental conditions similar in all cases and verified through the use of light measurement devices. The visors for the experiment were provided by the AFRL and were inspected regularly by the researcher to ensure consistent quality. The researcher used assistants from the AVTECH Research Corporation. These assistants had been trained in experiment methodology and instrument operations. The assistants were the same ones used by Silva in conduct of his study.

Validity

To ensure the accuracy of gathered data the researcher briefed each subject pilot on experiment conduct and the specifics of the Four Alternative Forced-Choice Target Detection Task. The researcher also ensured

environmental conditions were uniform and verified through the use of light measurement equipment and techniques. To ensure objective results, the direction of the target was selected randomly between each run. To ensure the haze index for each visor was constant, each visor was carefully inspected, controlled, and monitored by the researcher throughout the duration of the study.

The pilots used as the study population were all qualified in operational fighter test and trained in target detection and identification techniques. All the pilots had an uncorrected visual acuity of 20/20 or better.

Treatment of Data and Procedures

Data collected throughout this study applicable to statistical analysis consisted of ranges, measured in feet, at which test population pilots detected the model target.

To determine the effect of visor transmissivity on visual acuity in a low illumination environment, the following statistical hypothesis was tested: There is no difference in the visual target detection ranges among the test population pilots wearing no visor, the USAF standard visor, the VCATS 25% uncoated visor, the VCATS 35% uncoated visor, and the VCATS 50% uncoated visor.

To determine the effect of visor reflectivity on visual acuity in a low illumination environment, the following statistical hypothesis was tested: There is no difference in the visual target detection ranges among the test population pilots wearing a VCATS 25% uncoated visor and a VCATS 25% coated visor.

Data were recorded using the worksheet in Appendix C. It was subsequently entered into a Microsoft Excel spreadsheet for analysis. To

determine if there was a significant difference in the mean target detection ranges due to visor transmissivity, a *t* test was run on the data from the no visor, USAF standard visor, VCATS 25% uncoated visor, VCATS 35% uncoated visor, and the VCATS 50% uncoated visor. An α value of 0.05 was used. The data collected from each pilot during the three runs with a certain visor configuration was averaged and this was done for all 12 pilots wearing that visor configuration. These were the 12 data points that were used for the *t* test between the different visor configurations.

In determining if there was a significant difference in the mean detection ranges due to visor reflectivity, a *t* test was run on the data from the VCATS 25% uncoated visor and the VCATS 25% coated visor. An α value of 0.05 was used.

CHAPTER IV

RESULTS

Experimentation Process and Data

Data were collected at Nellis AFB, Nevada from June 2001 through August 2001. Experimentation was conducted on the flight line road outside the 422 TES main building. Only one pilot was tested per evening due to limited time to ensure the proper light boundary parameters. Each pilot completed 18 runs, three with each of the six visor configurations. The test population consisted of nine F-15C, one A-10, and two F-16 pilots for a total of 12. Average detection ranges for each pilot's experiment runs are listed in Table 6. The individual pilot test results are listed in Appendix D.

Table 6

Pilot's Average Target Detection Range (feet)

Pilot	No Visor	USAF Tinted	VCATS 25% Uncoated	VCATS 25% Coated	VCATS 35%	VCATS 50%
1	54.7	31.0	43.0	43.0	42.0	63.0
2	53.3	33.7	33.3	32.3	39.3	44.3
3	51.0	37.3	38.3	36.7	42.0	54.3
4	50.7	35.7	37.3	39.3	36.3	37.3
5	82.0	42.3	60.0	57.0	63.7	80.3
6	63.3	38.7	45.7	48.3	54.7	56.7
7	46.0	28.3	39.3	42.3	38.7	51.0
8	73.7	46.0	40.0	59.3	52.0	74.3
9	52.3	38.7	46.3	45.3	40.0	57.3
10	75.3	45.0	61.7	60.7	62.3	76.7
11	62.7	46.7	52.0	54.7	52.7	63.3
12	48.0	30.0	34.3	30.7	33.7	43.3
Avg.	**59.4**	**37.8**	**44.3**	**45.8**	**46.4**	**58.5**

Figure 8 depicts the mean target detection range for each of the six visor configurations.

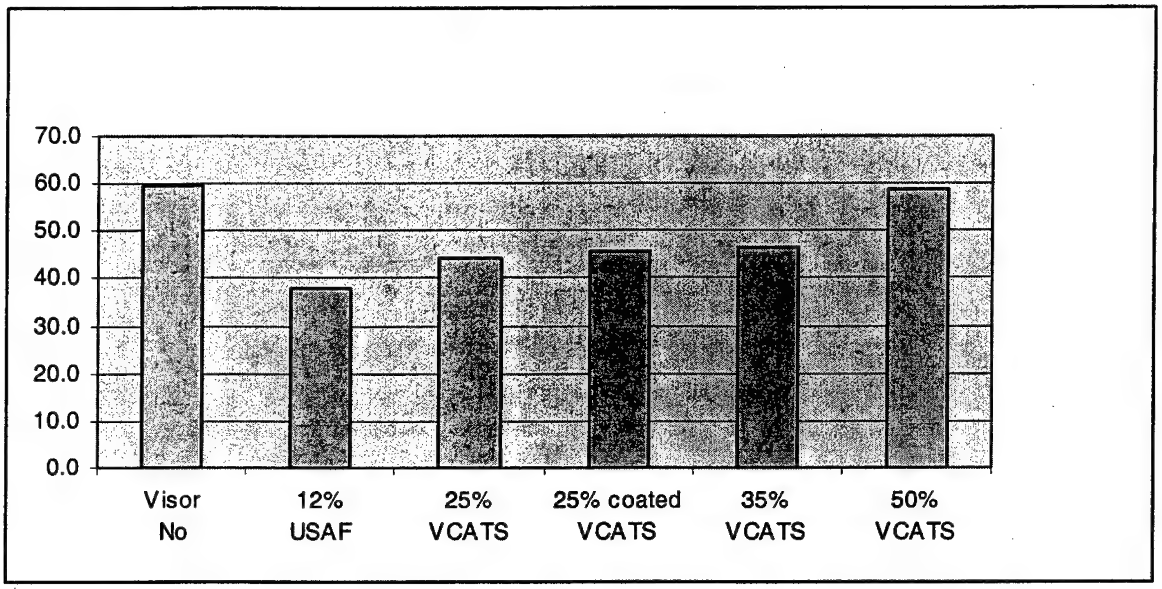


Figure 8. Mean Target Detection Range (feet).

Test runs were conducted in the early evening as the sun went behind the 422 TES building. This provided for light conditions substantially less than those used by Silva during his research in a high light environment, although the ratios of the three measured conditions were similar. Silva's light conditions were measured using the same equipment and techniques as this experiment. The light conditions in Silva's testing were a mean background luminance of 496 ft-Lamberts, a mean target luminance of 420.5 ft-Lamberts, and a mean ambient light luminance of 920.6 ft-Lamberts (Silva, 2001). The mean light conditions for this test were a mean background luminance of 83.7 ft-Lamberts, a mean target luminance of 65.2 ft-Lamberts, and a mean ambient luminance of 139.8 ft-

Lamberts. The Silva study yielded a target to background ratio of .85, a target to ambient light ratio of .46, and a background to ambient light ratio of .54. This study yielded a target to background ratio of .78, a target to ambient light ratio of .47, and a background to ambient light ratio of .60.

The percentage changes in target detection range are listed in Table 7. Bold type indicates a statistically significant difference based on a two-tailed *t* test using an α value of 0.05. Italics indicate decrease in percentage of detection range. *t* test results are listed at Appendix E.

Table 7

Percentage Change in Target Detection Range

From \ To	USAF 12%	VCATS 25% Uncoated	VCATS 25% Coated	VCATS 35%	VCATS 50%
No Visor	***36.42***	***25.48***	***22.91***	***21.83***	*1.54*
USAF 12%		**17.21**	**21.25**	**22.94**	**54.85**
VCATS 25% Uncoated			3.45	4.89	**32.12**
VCATS 25% Coated				1.39	**27.71**
VCATS 35%					**25.96**

Note. Bold face values indicate a statistically significant change ($\alpha = 0.05$), italics indicate a negative value.

Visor Transmissivity Results

In determining if visor transmissivity had significant effect on target detection range the hypothesis tested stated target detection range of USAF F-15C, A-10, and F-16 pilots would decrease as the transmissivity of the visor is decreased in a low illumination environment. The following visor configurations were used: no visor, USAF standard 12%, VCATS 25% uncoated, VCATS 35% uncoated, and a VCATS 50% uncoated. The percentage changes for each of the five visor configurations are listed in Table 8.

Table 8

Transmissivity Detection Range Percentages

To / **From**	**USAF 12%**	**VCATS 25% Uncoated**	**VCATS 35%**	**VCATS 50%**
No Visor	***36.42***	***25.48***	***21.83***	*1.54*
USAF 12%		**17.21**	**22.94**	**54.85**
VCATS 25% Uncoated			4.89	**32.12**
VCATS 35%				**25.96**

Note. Bold face values indicate a statistically significant change ($\alpha = 0.05$), italics indicate a negative value.

In determining the statistical significance of mean target detection range for each change in visor configuration, a two-tailed *t* test was performed on each of the 10 possible visor configuration pairings. These tests were run on Microsoft

Excel using an α value of 0.05 and 11 degrees of freedom. This yielded a critical value for *t* of 2.201. Values of *t* greater than 2.201 suggested a statistically significant difference in the mean target detection ranges of the paired visor configurations. Values of *t* less than 2.201 suggested statistical insignificance in the mean target detection ranges of the paired visor configurations by which the null hypothesis could not be rejected.

The *t* values for each of the 10 visor configuration comparison analysis are listed in Table 9. Specific *t* test results may be found at Appendix E. All but two pairings yielded *t* values in excess of 2.201. The pairing of no visor and the VCATS 50% visor produced a *t* value of 0.496. The pairing of the VCATS 25% uncoated visor and the VCATS 35% uncoated visor produced a *t* value of 1.500.

Table 9

Visor Transmissivity Comparison *t* Values

From / To	USAF 12%	VCATS 25% Uncoated	VCATS 35%	VCATS 50%
No Visor	**9.491**	**6.977**	**10.971**	0.496
USAF 12%		**3.205**	**4.547**	**6.966**
VCATS 25% Uncoated			1.500	**5.949**
VCATS 35%				**6.069**

Note. Bold face values indicate a statistically significant change ($\alpha = 0.05$)

Visor Reflectivity Results

In determining if visor reflectivity had significant effect on target detection range the hypothesis tested stated target detection range of USAF F-15C, A-10, and F-16 pilots would decrease as the reflectivity of the visor is increased in a low illumination environment. The following visor configurations were used: VCATS 25% uncoated and VCATS 25% coated. The percentage change for these visor configurations was an increase of 3.45% from the VCATS 25% uncoated to the VCATS 25% coated. In determining the statistical significance of mean target detection range of the two visor configurations, a two-tailed *t* test was performed. This was also run on Microsoft Excel using an α value of 0.05 and 11 degrees of freedom. This again yielded a critical value for *t* of 2.201. The *t* value calculated for this comparison was 0.876, suggesting no statistical significance exists between the mean target detection ranges of the VCATS 25% uncoated and VCATS 25% coated visor configurations and, therefore, the null hypothesis could not be rejected. Specific *t* test results may be found at Appendix E.

CHAPTER V

DISCUSSION

Study Limitations

It is important to understand the purpose and scope of this study and the inherent limitations in applicability to real-world implementation considerations prior to discussing the results. This study was conceived and developed as a follow on to a similar study conducted in a high illumination environment. Both studies were conducted in a similar fashion to allow result comparison, and possibly further statistical analysis between the two studies. The purpose of these studies was to quantitatively validate subjective data obtained from pilots during the Vista Sabre II and VCATS tests. To accomplish this, the experimental data gathering phase was set up as described earlier with close consultation from personnel at the AFRL. Inherent to the set up of these experiments was a limitation of resources available. This forced testing was limited to ground base and could not feasibly be conducted airborne. Also, airborne testing would cause dynamics that would be near impossible to quantify, whereas ground testing allowed for a more controlled environment in which variables could be controlled or eliminated.

Results from this study should be a consideration in the development of the Joint Helmet Mounted Cueing System, but taken in context as a limited fundamental core base of pilot visual acuity comparative data.

Visor Transmissivity

In determining if visor transmissivity had a statistically significant impact on a pilot's target detection range, specifically, a decrease in target detection range with a decrease in visor configuration transmissivity, the null hypothesis that there is no decrease in detection range with a decrease in visor transmissivity must be rejected. Five visor configurations were used for this comparison. They were, from most to least transmissive, no visor, VCATS 50%, VCATS 35%, VCATS 25% uncoated, and a standard USAF 12% visor. The transmissivity and average target detection range for each visor configuration are listed in Table 10.

Table 10

Visor Transmissivity and Average Target Detection Range

	Transmissivity	Target Detection Range (ft)
No Visor	100%	59.4
VCATS 50%	50%	58.5
VCATS 35%	35%	46.4
VCATS 25% Uncoated	25%	44.3
USAF Tinted	12%	37.8

The five visor configurations used yielded 10 possible pairings for transmissivity comparison analysis of a possible statisical significant difference in mean target detection range. The 10 comparisons are:

1. No visor to VCATS 50% visor

2. No visor to VCATS 35% visor
3. No visor to VCATS 25% uncoated visor
4. No visor to standard USAF 12% visor
5. VCATS 50% visor to VCATS 35% visor
6. VCATS 50% visor to VCATS 25% visor
7. VCATS 50% visor to standard USAF 12% visor
8. VCATS 35% visor to VCATS 25% visor
9. VCATS 35% visor to standard USAF 12% visor
10. VCATS 25% visor to standard USAF 12% visor

Transmissivity Analysis

No Visor to VCATS 50% Visor

The mean target detection range for the no visor configuration was 59.4 feet. The mean target detection range for the VCATS 50% visor configuration was 58.5 feet. Going from the no visor configuration to the VCATS 50% visor configuration decreased target detection range by 1.54%. The *t* test provided a *t* value of 0.496. Using an α value of 0.05, the corresponding value of *t critical* was 2.201. Since the value of *t* was smaller than the value of *t critical* the null hypothesis for this comparison could not be rejected, therefore, there is not a statistically significant difference in the pilots' mean target detection range wearing no visor and wearing the VCATS 50% visor.

No Visor to VCATS 35% Visor

The mean target detection range for the no visor configuration was 59.4 feet. The mean target detection range for the VCATS 35% visor configuration

was 46.4 feet. Going from the no visor configuration to the VCATS 35% visor configuration decreased target detection range by 21.83%. The *t* test provided a *t* value of 10.971. Using an α value of 0.05, the corresponding value of *t critical* was 2.201. Since the value of *t* was larger than the value of *t critical* the null hypothesis for this comparison could be rejected, therefore, there is a statistically significant difference in the pilots' mean target detection range wearing no visor and wearing the VCATS 35% visor.

<u>No Visor to VCATS 25% Uncoated Visor</u>

The mean target detection range for the no visor configuration was 59.4 feet. The mean target detection range for the VCATS 25% uncoated visor configuration was 44.3 feet. Going from the no visor configuration to the VCATS 25% uncoated visor configuration decreased target detection range by 25.48%. The *t* test provided a *t* value of 6.977. Using an α value of 0.05, the corresponding value of *t critical* was 2.201. Since the value of *t* was larger than the value of *t critical* the null hypothesis for this comparison could be rejected, therefore, there is a statistically significant difference in the pilots' mean target detection range wearing no visor and wearing the VCATS 25% uncoated visor.

<u>No Visor to Standard USAF 12% Visor</u>

The mean target detection range for the no visor configuration was 59.4 feet. The mean target detection range for the standard USAF 12% visor configuration was 37.8 feet. Going from the no visor configuration to the standard USAF 12% visor configuration decreased target detection range by 36.42%. The *t* test provided a *t* value of 9.491. Using an α value of 0.05, the

corresponding value of *t critical* was 2.201. Since the value of *t* was larger than the value of *t critical* the null hypothesis for this comparison could be rejected, therefore, there is a statistically significant difference in the pilots' mean target detection range wearing no visor and wearing the standard USAF 12% visor.

<u>VCATS 50% Visor to VCATS 35% Visor</u>

The mean target detection range for the VCATS 50% visor configuration was 58.5 feet. The mean target detection range for the VCATS 35% visor configuration was 46.4 feet. Going from the VCATS 50% visor configuration to the VCATS 35% visor configuration decreased target detection range by 25.96%. The *t* test provided a *t* value of 6.069. Using an α value of 0.05, the corresponding value of *t critical* was 2.201. Since the value of *t* was larger than the value of *t critical* the null hypothesis for this comparison could be rejected, therefore, there is a statistically significant difference in the pilots' mean target detection range wearing VCATS 50% visor and wearing the VCATS 35% visor.

<u>VCATS 50% Visor to VCATS 25% Uncoated Visor</u>

The mean target detection range for the VCATS 50% visor configuration was 58.5 feet. The mean target detection range for the VCATS 25% uncoated visor configuration was 44.3 feet. Going from the VCATS 50% visor configuration to the VCATS 25% uncoated visor configuration decreased target detection range by 32.12%. The *t* test provided a *t* value of 5.949. Using an α value of 0.05, the corresponding value of *t critical* was 2.201. Since the value of *t* was larger than the value of *t critical* the null hypothesis for this comparison could be rejected, therefore, there is a statistically significant difference in the pilots'

mean target detection range wearing VCATS 50% visor and wearing the VCATS 25% uncoated visor.

VCATS 50% Visor to Standard USAF 12% Visor

The mean target detection range for the VCATS 50% visor configuration was 58.5 feet. The mean target detection range for the standard USAF 12% visor configuration was 37.8 feet. Going from the VCATS 50% visor configuration to the standard USAF 12% visor configuration decreased target detection range by 54.85%. The *t* test provided a *t* value of 6.966. Using an α value of 0.05, the corresponding value of *t critical* was 2.201. Since the value of *t* was larger than the value of *t critical* the null hypothesis for this comparison could be rejected, therefore, there is a statistically significant difference in the pilots' mean target detection range wearing VCATS 50% visor and wearing the standard USAF 12% visor.

VCATS 35% Visor to VCATS 25% Uncoated Visor

The mean target detection range for the VCATS 35% visor configuration was 46.4 feet. The mean target detection range for the VCATS 25% uncoated visor configuration was 44.3 feet. Going from the VCATS 35% visor configuration to the VCATS 25% uncoated visor configuration decreased target detection range by 4.89%. The *t* test provided a *t* value of 1.500. Using an α value of 0.05, the corresponding value of *t critical* was 2.201. Since the value of *t* was smaller than the value of *t critical* the null hypothesis for this comparison could not be rejected, therefore, there is not a statistically significant difference in

the pilots' mean target detection range wearing the VCATS 35% visor and wearing the VCATS 25% uncoated visor.

VCATS 35% Visor to Standard USAF 12% Visor

The mean target detection range for the VCATS 35% visor configuration was 46.4 feet. The mean target detection range for the standard USAF 12% visor configuration was 37.8 feet. Going from the VCATS 35% visor configuration to the standard USAF 12% visor configuration decreased target detection range by 22.94%. The *t* test provided a *t* value of 4.547. Using an α value of 0.05, the corresponding value of *t critical* was 2.201. Since the value of *t* was larger than the value of *t critical* the null hypothesis for this comparison could be rejected, therefore, there is a statistically significant difference in the pilots' mean target detection range wearing VCATS 35% visor and wearing the standard USAF 12% visor.

VCATS 25% Uncoated Visor to Standard USAF 12% Visor

The mean target detection range for the VCATS 25% uncoated visor configuration was 44.3 feet. The mean target detection range for the standard USAF 12% visor configuration was 37.8 feet. Going from the VCATS 25% uncoated visor configuration to the standard USAF 12% visor configuration decreased target detection range by 17.21%. The *t* test provided a *t* value of 3.205. Using an α value of 0.05, the corresponding value of *t critical* was 2.201. Since the value of *t* was larger than the value of *t critical* the null hypothesis for this comparison could be rejected, therefore, there is a statistically significant

difference in the pilots' mean target detection range wearing VCATS 25%uncoated visor and wearing the standard USAF 12% visor.

Transmissivity Summary

Of the 10 visor pairings used for transmissivity comparison, all demonstrated a reduction in the pilots' ability to detect the target based on the mean target detection range of each visor configuration as transmissivity properties were reduced. Eight of the pairings were determined to have statistically significant reductions in target detection range. They were:

1. No visor to VCATS 35% visor
2. No visor to VCATS 25% uncoated visor
3. No visor to standard USAF 12% visor
4. VCATS 50% visor to VCATS 35% visor
5. VCATS 50% visor to VCATS 25% uncoated visor
6. VCATS 50% visor to standard USAF 12% visor
7. VCATS 35% visor to standard USAF 12% visor
8. VCATS 25% visor to standard USAF 12% visor

The two visor pairings determined not to have a statistically significant reduction in target detection range were:

1. No visor to VCATS 50% visor
2. VCATS 35% visor to VCATS 25% uncoated visor

It is interesting to note that during the conduct of the experiment runs, seven of the twelve pilots actually had an increase in mean target detection range when wearing the VCATS 50% visor compared to the no visor configuration.

The fact that no statistical significance was found for these two visor configuration pairings may be due in part to the limitations of the study. Light conditions were controlled within specified parameters, but were changing and often were below 100 ft-Lamberts which may have impacted the results. Based on the method upon which this study was conducted, no conclusive data or analysis can made because light readings were taken only after the first and final experimental runs for each pilot, only ensuring illumination was within boundary parameters. Another limitation of the study was the experimental population size. Limiting the population to 12 pilots and only three runs per visor configuration may not have yielded a large enough sample size to determine statistical significance in these two cases.

In the discussion of his study, Silva suggested that there may be a point visor light transmission properties are reduced to a point beyond which the continued reduction in transmissivity does not have a significant impact on target detection range. His study found no statistical significance in the difference in mean target detection range between the VCATS 25% uncoated visor and the standard USAF 12% visor (Silva, 2001). The results of this study would seem to dispute this finding in a low illumination environment.

Silva did find statistical significance in the difference in mean target detection range between the VCATS 35% visor and the VCATS 25% uncoated visor (Silva, 2001). This study found no statistical significance in the difference between these two configurations and found that 50% of the pilots actually had an increase in mean target detection range with the lower transmission VCATS

25% visor. Once again, the limitations of the experiment may be causal in the lack of significance discovery in this case; specifically, light conditions and population sample size.

Except for the comparisons between the no visor and VCATS 50% visor, and the VCATS 35% visor and VCATS 25% visor, the other eight comparisons support the hypothesis that the target detection range of USAF F-15C, A-10, and F-16 pilots would decrease as visor configuration transmissivity was decreased.

Visor Reflectivity

In determining if visor reflectivity had a statistically significant impact on a pilot's target detection range, specifically, a decrease in target detection range with an increase in visor configuration reflectivity, the null hypothesis that there is no decrease in detection range with an increase in visor reflectivity must be rejected. Two visor configurations were used for this comparison. They were the VCATS 25% uncoated visor with a reflectivity value of 4.0% and a VCATS 25% coated visor with reflectivity value of 6.5%. The reflectivity and average target detection range for each visor configuration are listed in Table 11.

Table 11

Visor Reflectivity and Average Target Detection Range

	Reflectivity	Target Detection Range (ft)
VCATS 25% Uncoated	4.0%	44.3
VCATS 25% Coated	6.5%	45.8

Reflectivity Analysis

VCATS 25% Uncoated Visor to VCATS 25% Coated Visor

The mean target detection range for the VCATS 25% uncoated visor configuration was 44.3 feet. The mean target detection range for the VCATS 25% coated visor configuration was 45.8 feet. Going from the VCATS 25% uncoated visor configuration to the VCATS 25% coated visor configuration actually increased target detection range by 3.45%. The *t* test provided a *t* value of 0.876. Using an α value of 0.05, the corresponding value of *t critical* was 2.201. Since the value of *t* was smaller than the value of *t critical* the null hypothesis for this comparison could not be rejected, therefore, there is not a statistically significant difference in the pilots' mean target detection range wearing the VCATS 25% uncoated visor and wearing the VCATS 25% coated visor.

Reflectivity Summary

While the results of the reflectivity analysis yield no statistical significance in the mean target detection range of pilots wearing the VCATS 25% uncoated and VCATS 25% coated visors, it is of interest to note the mean target detection range actually increased slightly as the reflectivity was increased. Five of the 12 pilots experienced an increase in average target detection range going from the uncoated to the coated visor. Once again, these results are inconclusive due to study limitations of light conditions and population sample size, but do show that under these conditions there is no statistical significance in target detection range between the two visor configurations.

Silva's study garnered similar results when comparing the reflectivity of the VCATS 25% uncoated visor to the VCATS 25% coated visor, although the mean target detection range did decrease by 2.71% when going from the uncoated to the coated visor. The visors used for this study were physically the same visors. Silva's results concluded that there was no statistical significance in the mean target detection range of pilots wearing the VCATS 25% uncoated and VCATS 25% coated visor in a relatively high illumination environment (Silva, 2001).

One possible explanation for why there was not a significant decrease in target detection range is that in a low light environment, the reflections off the pilot's face are minimized and thus do not distract or interfere with scene contrast and transmitted light. It should also be noted that study limitations of controlled light conditions and population sample size once again may have affected the results.

This study was conducted under very static conditions in comparison with the real-world environment in which these projection visors may be employed. A pilot employing a projection visor in a dynamic aerial environment will be exposed to varying sun angles and illumination intensity which may very well have distracting effects in comparison with study experimentation that included none of these dynamics. Also there was no projected image on the visors used during the study and this may also have an impact on pilots' target detection ranges based on distraction and interference.

CHAPTER VI

CONCLUSIONS

This study was conducted to experimentally determine the level of projection visor transmissivity and reflectivity impact on the visual detection range of fighter pilots in a low illumination environment such as dusk, dawn, or an overcast situation. This was accomplished by measuring pilot's target detection range while wearing each of six different visor configurations. The impetus for this study was to quantify the pilots' qualitative findings during VCATS and Vista Sabre II flight testing, as well as to compliment and amplify the findings of a similar study conducted in ahigh illumination environment. The findings of these two studies will be used by experts at AFRL in determining optimum helmet mounted display configuration for current and future fighter technology. The two areas of interest in this study were visor transmissivity effects and visor reflectivity effects.

Visor Transmissivity Effects

The results of the visor transmissivity study were consistent with expectations that pilot mean target detection range would decrease with a decrease in visor configuration transmission properties except for two cases. These cases were the no visor configuration to the VCATS 50% visor configuration and the VCATS 35% visor configuration to the VCATS 25% uncoated visor configuration. In both these cases, the difference in detection range was statistically insignificant as determined by this study.

It appears from the results of this study, that the VCATS 50% visor is the optimum configuration. Pilots who have flown the VCATS 50% visor in an actual application with projected symbology tend to experience ghosting effects. These ghosting effects seem to be worse as the intensity of the projection is brighter. In a low illumination environment the intensity of the projection may be reduced and this may solve the ghosting problem. Further research into this area will be required.

The VCATS 50% visor was not evaluated by Silva during the conduct of his study, thus no comparison to the high illumination environment results can be made at this time.

The second case results contrary to predicted hypothesis conditions was the VCATS 35% visor configuration to the VCATS 25% uncoated visor configuration. In this comparison, there was a 4.89% decrease in detection range, however, the results of the statistical analysis determined no statistical significance existed in this comparison. A possible explanation is that the 10% transmissivity reduction is insufficient to produce a significant difference in detection range in a low illumination environment. Based on the results of this study, no conclusive determination may be made as to the optimum configuration between the VCATS 35% visor and the VCATS 25% uncoated visor in a low illumination environment.

Silva determined there was a 5.84% drop in target detection range when comparing the results of the VCATS 35% visor to the VCATS 25% visor in a high illumination environment. Silva's statistical analysis, using the same *t* test and

values as used in this study, determined the difference was statistically significant (Silva, 2001). These results will have to be further evaluated and compared by personnel at AFRL to determine further research requirements.

Of note, no minimum detection range threshold was set for this study so results were not analyzed in that context. Further research would be required to determine a minimum detection range threshold. If this were to be accomplished, a cut-off line may be drawn and average detection ranges not meeting the threshold could be discarded. This would allow further research to concentrate efforts to a narrower field and thus provide an opportunity to expand sample size within established criteria.

Visor Reflectivity Effects

Two visor configurations were used to test the hypothesis that mean target detection range would decrease with an increase in visor reflectivity properties. A drop in mean target detection range between the VCATS 25% uncoated visor and the VCATS 25% coated visor was not evident. The mean target detection range actually increased by 3.45%. Statistical analysis determined this change to be statistically insignificant, however, it is interesting to note there was, although insignificant, an increase as opposed to a decrease in target detection range between these two configurations. The low illumination environment may not provide enough light to illuminate the pilots' facial features enough to cause distraction and a decrease in target detection range. Also, no projected symbology was present during this study and, therefore, no conclusion may be made as to those effects in a more dynamic environment.

Silva's study also determined there was no statistical significance in the reduction of mean target detection between the VCATS 25% uncoated and VCATS 25% coated visor configurations. A reduction of 2.71% was realized (Silva, 2001).

Based on this the results of this study, there is no difference in target detection due to reflective coating differences of the VCATS 25% uncoated and VCATS 25% coated visors. This does agree with results determined by Silva in his study, but is inconsistent with prior flight testing, AFRL research, and theoretical models.

CHAPTER VII

RECOMMENDATIONS

This study was conducted to collect quantifiable data with regard to projection visor transmissivity and reflectivity properties in a low illumination environment. Many of the dynamics of the air-to-air combat arena could not be duplicated and time and money constraints did not allow for full testing with projection imagery displayed on the visor. Based of the conclusions of this study and the Silva study, AFRL should be able to narrow the scope of interest in development, production, and procurement of the visor for the Joint Helmet Mounted Cueing System and future helmet mounted display technologies.

Based on the results of the VCATS 50% visor testing and finding of no statistical significance in mean target detection range between the no visor configuration and the VCATS 50% visor, the researcher recommends that the VCATS 50% visor configuration be tested under the same high illumination conditions as used in the Silva study. This would allow a comparison with high illumination transmissivity results. If the VCATS 50% visor is then found to be adequate for high illumination conditions, further flight testing should be accomplished with a visor possessing 50% transmission properties.

The researcher's final recommendation is based on results of the reflectivity analysis of both this and the Silva study. Both studies found the reflective properties of the visor studies to have no statistical significance in the pilot's mean target detection range. Based on these findings and the fact that the 50% transmissive visor may tend to present ghosting problems when flown with a

high intensity projected image, further research should be done with a reflective coated 50% transmissive visor. This may allow a lower intensity projected image to be sufficient for pilot viewing, eliminate ghosting, and maintain optimum configuration for mean target detection range.

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APPENDIX A

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APPENDIX B

ACRONYMS

ACRONYMS

ACC	Air Combat Command
AFB	Air Force Base
AFRL	Air Force Research Laboratory
AL	Armstrong Laboratory
CRT	Cathode Ray Tube
FCR	Fire Control Radar
HMS	Helmet Mounted Sight
HMD	Helmet Mounted Display
HMT/D	Helmet Mounted Tracker and Display
HOBA	High off-boresight angle
HUD	Heads Up Display
JHMCS	Joint Helmet Mounted Cueing System
TES	Test and Evaluation Squadron
USAF	United States Air Force
USN	United States Navy
VCATS	Visually Coupled Acquisition and Targeting System

APPENDIX C

DATA COLLECTION DEVICE

DATA COLLECTION SHEET

Pilot #: ____________________ Date: ____________________

Start time: ________________ Finish time: ________________

Conditions: ____

No Visor		Stand USAF		25% VCATS		25% VCATS (c)		35% VCATS		50% VCATS	
Seq		**Seq**		**Seq**		**Seq**		**Seq**		**Seq**	
Run 1											
Aspect											
Dist											
Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd	
Target		Target		Target		Target		Target		Target	
Barium		Barium		Barium		Barium		Barium		Barium	
Run 2											
Aspect											
Dist											
Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd	
Target		Target		Target		Target		Target		Target	
Barium		Barium		Barium		Barium		Barium		Barium	
Run 3											
Aspect											
Dist											
Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd	
Target		Target		Target		Target		Target		Target	
Barium		Barium		Barium		Barium		Barium		Barium	

APPENDIX D

INDIVIDUAL TEST RESULTS

Table 12

Pilot 1 Results

Run	**No Visor**	**USAF Tinted**	**VCATS 25%**	**VCATS 25% coated**	**VCATS 35%**	**VCATS 50%**
Sequence	1	3	5	6	4	2
1	61	41	40	45	45	75
2	56	24	45	41	37	57
3	47	28	44	43	44	57
Avg	54.7	31.0	43.0	43.0	42.0	63.0
Lighting						
Background	113			79		
Target	95			64		
Barium	188			136		

Table 13

Pilot 2 Results

Run	**No Visor**	**USAF Tinted**	**VCATS 25%**	**VCATS 25% coated**	**VCATS 35%**	**VCATS 50%**
Sequence	6	1	5	4	3	2
1	55	38	33	32	38	50
2	53	31	35	32	39	36
3	52	32	32	33	41	47
Avg	53.3	33.7	33.3	32.3	39.3	44.3
Lighting						
Background	43	85				
Target	39	73				
Barium	71	140				

Table 14

Pilot 3 Results

Run	No Visor	USAF Tinted	VCATS 25%	VCATS 25% coated	VCATS 35%	VCATS 50%
Sequence	2	5	3	4	1	6
1	51	35	40	39	42	59
2	51	41	37	35	39	52
3	51	36	38	36	45	52
Avg	51.0	37.3	38.3	36.7	42.0	54.3
Lighting						
Background					72	57
Target					68	42
Barium					138	87

Table 15

Pilot 4 Results

Run	No Visor	USAF Tinted	VCATS 25%	VCATS 25% coated	VCATS 35%	VCATS 50%
Sequence	5	6	3	4	1	2
1	51	36	36	40	38	34
2	51	36	39	39	35	38
3	50	35	37	39	36	40
Avg	50.7	35.7	37.3	39.3	36.3	37.3
Lighting						
Background		73			104	
Target		49			71	
Barium		113			148	

Table 16

Pilot 5 Results

Run	No Visor	USAF Tinted	VCATS 25%	VCATS 25% coated	VCATS 35%	VCATS 50%
Sequence	5	1	3	2	6	4
1	82	43	61	55	65	78
2	87	44	59	56	63	81
3	77	40	60	60	63	82
Avg	82.0	42.3	60.0	57.0	63.7	80.3
Lighting						
Background		100			66	
Target		70			46	
Barium		150			109	

Table 17

Pilot 6 Results

Run	No Visor	USAF Tinted	VCATS 25%	VCATS 25% coated	VCATS 35%	VCATS 50%
Sequence	6	1	2	3	4	5
1	70	40	45	45	54	67
2	75	38	46	50	56	53
3	45	38	46	50	54	50
Avg	63.3	38.7	45.7	48.3	54.7	56.7
Lighting						
Background	72	133				
Target	55	101				
Barium	142	280				

Table 18

Pilot 7 Results

Run	No Visor	USAF Tinted	VCATS 25%	VCATS 25% coated	VCATS 35%	VCATS 50%
Sequence	1	2	3	4	5	6
1	45	30	42	43	30	59
2	44	24	35	42	41	43
3	49	31	41	42	45	51
Avg	46.0	28.3	39.3	42.3	38.7	51.0
Lighting						
Background	118					72
Target	83					54
Barium	186					122

Table 19

Pilot 8 Results

Run	No Visor	USAF Tinted	VCATS 25%	VCATS 25% coated	VCATS 35%	VCATS 50%
Sequence	4	2	6	5	1	3
1	71	41	34	55	44	65
2	65	47	41	65	56	87
3	85	50	45	58	56	71
Avg	73.7	46.0	40.0	59.3	52.0	74.3
Lighting						
Background			68		108	
Target			54		83	
Barium			103		174	

Table 20

Pilot 9 Results

Run	No Visor	USAF Tinted	VCATS 25%	VCATS 25% coated	VCATS 35%	VCATS 50%
Sequence	3	2	4	5	1	6
1	54	41	46	50	39	57
2	51	37	49	47	41	57
3	52	38	44	39	40	58
Avg	52.3	38.7	46.3	45.3	40.0	57.3
Lighting						
Background					106	75
Target					83	65
Barium					186	117

Table 21

Pilot 10 Results

Run	No Visor	USAF Tinted	VCATS 25%	VCATS 25% coated	VCATS 35%	VCATS 50%
Sequence	3	5	4	6	2	1
1	77	55	65	65	62	75
2	77	30	65	60	65	75
3	72	50	55	57	60	80
Avg	75.3	45.0	61.7	60.7	62.3	76.7
Lighting						
Background				62		106
Target				49		85
Barium				100		175

Table 22

Pilot 11 Results

Run	No Visor	USAF Tinted	VCATS 25%	VCATS 25% coated	VCATS 35%	VCATS 50%
Sequence	6	1	4	3	5	2
1	65	46	53	52	51	63
2	63	46	52	55	53	66
3	60	48	51	57	54	61
Avg	62.7	46.7	52.0	54.7	52.7	63.3
Lighting						
Background	87	120				
Target	62	105				
Barium	165	188				

Table 23

Pilot 12 Results

Run	No Visor	USAF Tinted	VCATS 25%	VCATS 25% coated	VCATS 35%	VCATS 50%
Sequence	3	4	2	1	6	5
1	48	32	35	31	30	39
2	48	29	34	29	36	49
3	48	29	34	32	35	42
Avg	48.0	30.0	34.3	30.7	33.7	43.3
Lighting						
Background				51	39	
Target				37	36	
Barium				82	56	

APPENDIX E

t Test Results

Table 24

No Visor and VCATS 50% Visor

	No visor	VCATS 50%
Mean	59.41667	58.5
Variance	141.8005	187.101
Observations	12	12
Pearson Correlation	0.883789	
Hypothesized Mean Difference	0	
df	11	
t Stat	0.495964	
P(T<=t) two-tail	0.62968	
t Critical two-tail	2.200986	

Table 25

No Visor and VCATS 35% Visor

	No visor	VCATS 35%
Mean	59.41667	46.44444
Variance	141.8005	103.9865
Observations	12	12
Pearson Correlation	0.942969	
Hypothesized Mean Difference	0	
df	11	
t Stat	10.97106	
P(T<=t) two-tail	2.91E-07	
t Critical two-tail	2.200986	

Table 26

No Visor and VCATS 25% Uncoated Visor

	No visor	VCATS 25% uncoated
Mean	59.41667	44.27778
Variance	141.8005	87.45118
Observations	12	12
Pearson Correlation	0.775685	
Hypothesized Mean Difference	0	
df	11	
t Stat	6.97723	
P(T<=t) two-tail	2.34E-05	
t Critical two-tail	2.200986	

Table 27

No Visor and Standard USAF 12% Visor

	No visor	std USAF 12%
Mean	59.41667	37.77778
Variance	141.8005	39.84512
Observations	12	12
Pearson Correlation	0.793386	
Hypothesized Mean Difference	0	
df	11	
t Stat	9.491342	
P(T<=t) two-tail	1.24E-06	
t Critical two-tail	2.200986	

Table 28

VCATS 50% Visor and VCATS 35% Visor

	VCATS 35%	VCATS 50%
Mean	46.44444	58.5
Variance	103.9865	187.101
Observations	12	12
Pearson Correlation	0.873706	
Hypothesized Mean Difference	0	
df	11	
t Stat	-6.069	
P(T<=t) two-tail	8.09E-05	
t Critical two-tail	2.200986	

Table 29

VCATS 50% Visor and VCATS 25% Uncoated Visor

	VCATS 25% uncoated	VCATS 50%
Mean	44.27778	58.5
Variance	87.45118	187.101
Observations	12	12
Pearson Correlation	0.805065	
Hypothesized Mean Difference	0	
df	11	
t Stat	-5.94866	
P(T<=t) two-tail	9.61E-05	
t Critical two-tail	2.200986	

Table 30

VCATS 50% Visor and Standard USAF 12% Visor

	std USAF 12%	VCATS 50%
Mean	37.77778	58.5
Variance	39.84512	187.101
Observations	12	12
Pearson Correlation	0.699351	
Hypothesized Mean Difference	0	
df	11	
t Stat	-6.96641	
P(T<=t) two-tail	2.37E-05	
t Critical two-tail	2.200986	

Table 31

VCATS 35% Visor and VCATS 25% Uncoated Visor

	VCATS 25% uncoated	VCATS 35%
Mean	44.27778	46.44444
Variance	87.45118	103.9865
Observations	12	12
Pearson Correlation	0.872459	
Hypothesized Mean Difference	0	
df	11	
t Stat	-1.4999	
P(T<=t) two-tail	0.161784	
t Critical two-tail	2.200986	

Table 32

VCATS 35% Visor and Standard USAF 12% Visor

	std USAF 12%	VCATS 35%
Mean	37.77778	46.44444
Variance	39.84512	103.9865
Observations	12	12
Pearson Correlation	0.778603	
Hypothesized Mean Difference	0	
df	11	
t Stat	-4.54694	
P(T<=t) two-tail	0.000834	
t Critical two-tail	2.200986	

Table 33

VCATS 25% Uncoated Visor and Standard USAF 12% Visor

	std USAF 12%	VCATS 25% uncoated
Mean	37.77778	44.27778
Variance	39.84512	87.45118
Observations	12	12
Pearson Correlation	0.660285	
Hypothesized Mean Difference	0	
df	11	
t Stat	-3.20545	
P(T<=t) two-tail	0.008373	
t Critical two-tail	2.200986	

Table 34

VCATS 25% Uncoated Visor and VCATS 25% Coated Visor

	VCATS 25% uncoated	VCATS 25% coated
Mean	44.27778	45.80556
Variance	87.45118	106.3931
Observations	12	12
Pearson Correlation	0.815743	
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.87631	
P(T<=t) two-tail	0.399592	
t Critical two-tail	2.200986	